## **Contents**

## Preface — v

1	Introduction —— 1
1.1	Brain: structure and function principles —— 1
1.2	Artificial neural networks —— 4
1.2.1	Neuron models —— 4
1.2.2	Feedforward networks —— 5
1.2.3	Recurrent neural networks —— 6
1.3	Recurrent neural networks of associative memory —— 7
1.4	Hopfield network model —— 8
1.5	Learning of neural networks —— 9
1.5.1	The simplest learning algorithms for feedforward networks —— 10
1.5.2	Learning algorithms for recurrent networks —— 13
1.5.3	Learning, function approximation, and support vector machines —— 16
1.5.4	Statistical theory of learning —— 17
1.6	Oscillatory neural networks and synchronization —— 18
1.6.1	Synchronous oscillations of neural activity in the brain and neural
	oscillators —— 18
1.6.2	Synchronizable oscillatory networks —— 20
1.6.3	Networks of pulsed neurons —— 22
1.6.4	Signal processing and communication via chaos
	synchronization —— 23
1.7	Complicated networks —— 26
1.8	Multi-agent systems —— 28
1.8.1	Multi-agent modeling —— 28
1.8.2	Reinforcement learning for multi-agent systems —— 29
1.9	Wireless networks and cognitive dynamical systems —— 29
1.10	Quantum and classical quantum-inspired parallel computational
	algorithms —— 32
1.10.1	Photonic one-way quantum computations —— 32
1.10.2	Quantum-inspired neural networks and evolutionary algorithms —— 33
2	Neural and oscillatory networks of associative memory —— 39
2.1	Neural networks of associative memory ——— 39
2.1.1	Types of associative memory networks —— 39
2.1.2	Random neural networks and the statistical macrodynamics
	approach —— 41
2.1.3	Macrodynamical approach for associative memory networks —— 44
21/	Macrodynamical analysis of the memory retrieval process —— 47

2.2	Oscillatory networks of associative memory —— 51
2.2.1	Problem of the design of oscillatory associative memory
	networks —— 51
2.2.2	Systems of globally homogeneously coupled limit cycle
	oscillators —— 53
2.2.3	Associative memory networks of limit-cycle oscillators —— 58
2.2.4	Oscillatory media related to networks of limit cycle oscillators —— 67
2.2.5	Associative memory networks of complex-valued neurons —— 70
3	Oscillatory networks for modeling the brain structures performance —— 75
3.1	Motivations for oscillatory network modeling —— 75
3.2	Oscillatory network models for the olfactory and auditory brain systems —— 75
3.2.1	System of two coupled oscillatory networks for modeling the olfactory
	brain system functioning —— 75
3.2.2	Oscillatory network approach to segmentation of mixed interfering
	acoustic streams —— 78
3.3	Oscillatory network models for visual image processing tasks —— 80
3.3.1	Oscillatory model by Malsburg and Buhmann —— 80
3.3.2	Model LEGION by Wang and Terman —— 81
3.3.3	Three-dimensional columnar neural network model by Li —— 83
3.4	Pure oscillatory network model for image processing tasks —— <b>85</b>
3.4.1	Known data on the brain visual cortex taken into account in the
	oscillatory network model —— <b>86</b>
3.4.2	Three-dimensional oscillatory network of columnar architecture —— 87
3.4.3	Biologically inspired model of single network oscillator —— 88
3.4.4	Self-organized dynamical network coupling —— 90
3.4.5	Reduced two-dimensional oscillatory network —— 91
3.4.6	Brightness image segmentation via the reduced oscillatory network —— 92
3.4.7	Texture segmentation and contour integration —— 95
3.4.8	Comparison of the model with other oscillatory network models —— 96
3.5	Oscillatory network models including visual attention —— 98
3.5.1	Oscillatory model by Labbi, Milanese, and Bosch —— 98
3.5.2	Oscillatory neural network model by Borisyuk and Kazanovich —— 99
4	Image processing based on the oscillatory network model —— 103
4.1	Problems of image segmentation and traditional methods of their
	solution —— 103
4.1.1	Digital images and methods of image analysis —— 103
4.1.2	Image segmentation problems and the examples of their solution via
	traditional methods of computer vision —— 106

4.1.3	Neuromorphic methods of image processing —— 108
4.2	Oscillatory network model description —— 109
4.2.1	Network architecture and governing dynamical system —— 109
4.2.2	Modified model of network oscillator —— 110
4.2.3	Modified principles of network coupling —— 112
4.2.4	Network performance and model capabilities —— 113
4.2.5	Image fragment separation from a visual scene —— 118
4.3	Relation of the oscillatory network method to other approaches —— 12:
4.3.1	Relation of the model to controllable dynamical systems —— 121
4.3.2	Relation of the model to multi-agent systems —— 122
4.4	Hardware implementation of oscillatory networks —— 123
4.5	Code providing computer experiments on image processing —— 124
5	Parallel information processing and photon echo —— 127
5.1	Properties of the photon echo effect —— 127
5.2	Time processing of optical signals in photon echo processors —— 129
5.3	Implementation of vector—matrix multiplier based on photon echo —— 130°
5.3.1	Photon echo vector-matrix multiplier with spatial integration —— 132
5.3.2	A holographic photon echo VMM scheme with spatial integration —— 133
5.3.3	Estimates of the main technical characteristics of digital echo
	processors —— 135
5.4	Optical implementation of neural networks based on photon
	echo <b>—— 136</b>
5.4.1	Outer product scheme for optical neural networks —— 136
5.4.2	Inner product scheme for optical neural networks —— 138
5.4.3	Inner product scheme for 2D array processing —— 139
6	Stochastic oscillators for modeling polarized light beams —— 142
6.1	Polarization analysis of quasimonochromatic light beams —— 142
6.1.1	Classical description of plane electromagnetic wave —— 142
6.1.2	Polarization analysis in terms of coherence matrix —— 143
6.1.3	Classical and quantum correlations in optics —— 146
6.2	Modeling superpositions of polarized light beams —— 147
6.2.1	Oscillatory model of polarized light beam —— 147
6.2.2	Modeling the action of a polarizer —— 150
6.2.3	Construction of superpositions of quasimonochromatic light
	beams —— <b>152</b>
6.3	Outline of the design of feedforward network of stochastic
	oscillators —— 155

xii — Contents

Summary and some perspectives —— 157

Index —— **159**